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USE OF COAL-COMBUSTION BY-PRODUCTS STATUS AND OPPORTUNITIES IN REGION 8

U.S. Department of Energy Region 8

COLORADO, MONTANA, NORTH DAKOTA,
SOUTH DAKOTA, UTAH, and WYOMING

Prepared by:

Tim Bryggman and Jim Nallick,
Associated Western Universities Fellowship
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Copies of this report are available from the Montana Department of Natural Resources and Conservation - Energy Division, 1520 East 6th Avenue, Helena, MT, 59620-2301. Any questions should be directed to Ann-Marie Gritzuk at the above address (phone 406-444-6697).

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GENERAL OVERVIEW

The findings in this paper indicate that ash and other by-products from coal combustion can be used to save energy, increase economic activity, and reduce the need to dispose of these materials as waste. Coal-combustion by-products typically include fly ash, bottom ash, boiler slag, and desulfurization products. Numerous technical studies and successful use of coal-combustion by-products in a broad range of applications show that these materials can be used for various beneficial purposes, especially in concrete and road construction.

Approximately 8.6 million tons of coal-combustion by-products are produced annually in the region, of which approximately 12 percent currently are used (see Appendix A). Nationwide, 20 percent of 87 million tons of combustion by-products are used (see Appendix B). The remaining coal-combustion by-products are disposed of in landfills or by other means, increasing disposal costs and possible environmental problems.

This report encourages state energy officials in Region 8 to actively promote the use of coal-combustion by-products. The authors have identified the amount and types of by-products produced in each state, their current use, and opportunities for further use.

Brief Description of Coal-Combustion By-products and Applications

By-products from the combustion of coal are produced in different parts of the boiler and by different types of pollution control equipment, resulting in varied chemical composition. The physical characteristics of these combustion materials range from fine powder to a wet sludge.

By far the most researched application and widespread use of a coal-combustion by-product is the use of fly ash in concrete. Fly ash also is used as a mineral filler in asphalt.

Bottom ash and boiler slag often are used as a direct substitute for sand, because of their similarities to sand in both size and composition. Application to snow and ice on roads is a common use. They also are used as sand blasting grit and roofing granules.

Flue gas desulfurization (FGD) products are produced by air pollution control equipment. FGD sludge is not much used but research on its potential use is increasing, largely because more stringent clean air standards could produce even more FGD products in the future. At present, use as a road base material is a promising application. Due to its high gypsum content, FGD sludge also is used in manufacturing wallboard.

Impetus to Use Coal-Combustion By-products

The use of coal-combustion by-products conserves energy and natural resources, stimulates economic activity and provides an alternative to current by-product disposal practices. Using fly ash as a partial replacement for cement in concrete saves large amounts of energy by avoiding the need to produce the cement. This energy savings can be considerable because cement manufacturing is a highly energy-intensive process. Substituting fly ash for cement also reduces the need to mine the minerals required for cement, thereby saving energy, conserving natural resources and avoiding the costs of obtaining the minerals. In many other applications, the use of coal-combustion by-products provides an inexpensive alternative to materials that require costly extraction and processing.

Promoting the use of coal-combustion by-products also encourages new economic activity and generates new business opportunities. Existing businesses can benefit from substitution of coal-combustion by-products for more expensive materials. By-products also can replace natural resources imported from other states, thus increasing the competitive advantage of local businesses. Value-added use of coal-combustion by-products adds to a more sustainable local economy and new business opportunities.

Finally, the use of these by-products can reduce disposal costs and help offset the costs of generating electricity for coal-burning power plants.

TECHNICAL DESCRIPTION OF COAL-COMBUSTION BY-PRODUCTS

When coal is burned in a power plant boiler to produce electricity, the non-combustible minerals in the coal form ash. The physical and chemical properties of coal ash vary widely depending upon the type of coal being burned and the type of equipment used for combustion and pollution control.

Bottom ash is a sand-like material containing large amounts of silica and alumina that clump together in a molten state and fall to the bottom of the boiler; hence the name "bottom" ash. Boiler slag is the ash that clings to the interior surfaces of the boiler. Periodically the slag is knocked down to the bottom of the boiler where it is removed along with the bottom ash. In most situations, and in this report, no distinction is made between bottom ash and boiler slag.

Fly ash is a very fine white or light colored material similar in chemical composition to bottom ash. This ash remains suspended in the flue gas exiting the boiler. Anti-pollution devices must be used to prevent the fly ash from escaping the plant. The most common method of accomplishing this is the use of an electrostatic precipitator (ESP). Fabric filters, scrubbers, and mechanical collectors also are used (Baker M., 1984).

After the fly ash has been removed from the flue gas, air polluting gases such as sulfur dioxide (SO_2) still remain in the stack. An increasing number of utilities are removing SO_2 through a flue gas desulfurization process. The wet scrubber method of desulfurizing flue gas uses lime as a reagent to chemically bond with the sulfur. Lime water is misted through the stack gases, creating a slurry. The resulting slurry (FGD sludge) can be very high in gypsum content.

Sulfur dioxide (SO_2) also can be removed by newer methods. These methods, known as Advanced SO_2 Control, typically use dry techniques to extract sulfur from the flue gas. The reagents in this process combine with the sulfur to produce calcium sulfite and calcium sulfate (gypsum) in the fly ash. These reagents can create difficulties for efforts to use the ash for some purposes, but may present other opportunities.

The type of boiler being used has a large effect on the physical properties and quantities of the ash produced from a given coal. In large power plants, two types of boilers are commonly used: pulverized coal (PC) boilers, and cyclone boilers (Baker M., 1984). Ratios of fly ash to bottom ash vary from plant to plant. A PC boiler may produce 20 percent bottom and 80 percent fly ash. A cyclone boiler commonly produces 90 percent bottom and 10 percent fly ash (Baker M., 1984). Nationwide, PC boilers are the most common; hence, 75 percent of all ash collected is fly ash (see Appendix B).

The American Society for Testing and Materials (ASTM) classifies fly ash as "F" or "C" according to ASTM C 618 - the standard specification for fly ash used in concrete. The type of ash that is produced is partly determined by the coal being burned. Anthracite and bituminous coal in the eastern United States normally produces an ASTM Class F fly ash. Class F ash has "pozzolanic" properties; pozzolanic material has no cementitious properties of its own, but in the presence of the lime and water in portland cement it will harden and contribute strength to the concrete mixture.

The lignite and sub-bituminous coal in the western United States normally produce an ASTM Class C fly ash. Besides contributing strength to concrete by pozzolanic action, Class C fly ash is self-hardening and may not require the addition of lime or cement for nonstructural, low strength applications.

Other information is needed along with the ASTM classification to develop a complete picture of ash quality. Some fly ash meets ASTM requirements for both classifications and some

does not meet either. Knowing the calcium and carbon content can give a good indication of the quality of an ash. In general, high calcium content and low carbon content are desirable. Calcium content, expressed in terms of calcium oxide (CaO), is considered low at less than 10 percent and high in the range of 10 percent to 30 percent (Kosmatka, 1990). Carbon content, as measured by percent loss on ignition (LOI), will normally be less than 1 percent for a high quality ash.

FEDERAL GOVERNMENT ACTION

In 1983, The Resource Conservation and Recovery Act (RCRA) called on the Environmental Protection Agency (EPA) to:

> *conduct a detailed and comprehensive study and submit a report on the adverse effects on human health and the environment, if any, of the disposal and utilization of fly ash waste, bottom ash waste, slag waste, flue gas emission control waste, and other by-product materials generated primarily from the combustion of coal or other fossil fuels.*

This information was compiled in a 1988 report to Congress (EPA, 1988).

Coal-combustion by-products are composed predominantly of common harmless minerals and elements. However, there also are trace amounts of metals, salts, and radionuclides. For example, western coal tends to have higher concentrations of boron, while radionuclides are more common in eastern coals. Concentrations of trace elements vary in by-product resources depending on the type of coal used and the coal combustion technique employed (EPRI, 1989).

In situations where by-products may come in contact with water, leaching of coal-combustion by-products can pose environmental problems for disposal or use of the by-product. While high pH of coal by-products prevents many trace elements from dissolving in surface water and groundwater, combining coal ash with more acidic materials can enhance the dissolution of harmful constituents. Potential harm to the environment can be reduced by project design that minimizes water contact with the ash. Using coal-combustion by-products in cementitious materials chemically locks up potentially toxic elements, preventing them from leaching into groundwater. Individuals with concerns about metals content in coal ash should note that EPA's "best developed available technology" for stabilizing metal-bearing and cyanide-containing wastes is the application of a lime and fly ash mixture (American Coal Ash Association, 1992).

It is difficult to develop a single management plan to cover all potential uses for such a variable product. The EPA report to Congress recommended classification of coal by-products as non-hazardous, leaving individual states with the responsibility to develop solid waste programs that address the concerns associated with their specific coal by-products (EPA, 1988).

EPA also produced a set of guidelines for the procurement of cement and concrete containing fly ash. These guidelines include: (1) eliminating from specifications any discrimination against the use of recovered materials; (and) (2) purchasing products which contain recovered material if reasonable levels of technical performance, cost, availability, and competition can be achieved (Federal Register, 1983). RCRA defines procuring agencies "to include not only Federal agencies, but also State and local agencies, grantees, and contractors which are using Federal funds to purchase cement and concrete" (Federal Register, 1983). These regulations apply to "items where the purchase price of the item exceeds $10,000, or where the quantity of such items purchased during the preceding year exceeded $10,000."

BY-PRODUCT APPLICATIONS

There are many technically feasible applications for coal ash and FGD sludge. A large percentage of these applications use coal-combustion by-products as a construction material, or as a component in producing construction materials.

Concrete and Asphalt Paving

The most common application of coal-combustion by-products has been the use of fly ash to replace cement in concrete. Nationwide in 1989, 76 percent of fly ash sales were to the concrete industry (see Appendix B). Standard concrete is made by combining sand, coarse aggregate, cement and water. The most expensive material in concrete is cement. In many applications it is acceptable to replace up to 20 percent of the cement with fly ash, which generally costs about half the price of cement.

This is an ideal application of fly ash, as it reduces the cost of the concrete and often favorably enhances the physical properties of the fresh and hardened concrete. The spherical shape of fly ash particles improves the workability and finishability of concrete. The early strength of fly ash concrete tends to be lower than normal concrete, but long term strength is often higher. This delayed strength gain is a major factor in determining how much fly ash to use in a specific situation.

It has been estimated that if all the concrete made in the United States contained fly ash at a 20 percent replacement rate, only about 23 percent of the fly ash produced would be used (American Coal Ash Association, 1991). Higher replacement rates are being researched as a way of using more fly ash. Coal Creek Power Station in North Dakota has successfully used a 70 percent replacement rate for projects on the plant site (GAI vol 2, 1992). Besides using much more fly ash, a 70 percent replacement rate in all concrete would save nearly three billion dollars annually in the cost of producing cement and disposing of fly ash (University of Wisconsin, 1992).

Roads and other structures have been built with fly ash concrete for many years. State departments of transportation are continually involved in large concrete projects and could become prominent users of fly ash in concrete. The amount of fly ash concrete used in road projects varies from state to state. In southern Utah, use of Class F fly ash use is mandatory where it counters the negative effects of the alkaline aggregate that is common in the area.

A hindrance to significantly increasing ash use in concrete applications is that much of the ash being produced does not meet current ASTM standards. Fly ash may be unsuited for use in concrete because of high carbon content, contamination by chemicals from the pollution control process, or any number of other variables. In these situations, other uses may be more appropriate. Using fly ash as a mineral filler in asphalt paving is an example of this.

High Volume Applications

Clearly, concrete products and asphalt can not be expected to use all of the coal-combustion by-products. The remainder is available for use in other "high volume" applications. High volume applications typically produce a marketable product that includes at least 50 percent coal-combus-

tion by-products. High volume applications currently under development include the following:

* Slurry backfills
* Grouting
* Fills
* Waste stabilization
* Subgrade stabilization
* Pavement base course
* Roller compacted concrete

EPRI has performed extensive research aimed at high volume applications, particularly in the road construction industry. A major accomplishment of this research has been the 1992 publishing by EPRI of a two volume design manual entitled Fly Ash Design Manual for Road and Site Applications. This manual contains a wealth of technical information and field studies that a designer can use to assist in the planning of construction projects using large quantities of ash.

Slurry backfills and grouting: Slurry backfills, or flowable fill, is essentially a very low strength concrete used primarily for backfilling trenches, such as those that are dug for water lines, sewer, telephone cable or electrical wire. It typically is made by mixing fly ash and water, with relatively small amounts of sand and cement if necessary; some Class C ash will develop enough strength to form a competent fill without the addition of any cement (GAI vol 2, 1992). It is important that the mix be designed to have a strength low enough so that it can easily be excavated to allow for maintenance.

Flowable fills are gaining popularity as more experience is gained with the material. Because it is poured into place, it often has the advantage of being faster and less expensive than compacted soil backfills (GAI vol 2, 1992).

Grouting is the process of injecting concrete into voids that are not accessible by other means (GAI vol 2, 1992). Fly ash is an excellent material for grout because its spherical particle shape makes the grout more flowable, and its pozzolanic properties add strength.

Because of these advantages, fly ash has been used in grout since the 1940s (GAI vol 2, 1992). Filling voids around oil well casings is just one of many uses of grout. Near Beulah, North Dakota, 5500 tons of Class C fly ash were used to grout a mine (GAI vol 2, 1992). As grouting techniques become increasingly sophisticated, grouting will become increasingly important as a use of coal ash.

Marketers in the region see a strong prospect in the market for slurried fills and grouting. The flowable and pozzolanic characteristics of fly ash make it a better material than its competitors: soil, sand and cement. One aspect of this superiority is a more workable material which results in labor cost savings for the user. The advantages of flowable fills and grouting have the potential to provide an attractive high volume market for fly ash. With increasing environmental concern over underground storage tanks, oil wells and mines, demand for effective methods of filling voids is expected to increase.

Fills: Fly ash fills and embankments for road and other construction projects are a relatively new technology in North America. An EPRI project search located 64 projects in the United States and Canada, each of which used between 1,800 and 3 million cubic yards of fly ash (GAI vol 1, 1992).

Construction techniques for building a load-bearing fill with ash are similar to those with conventional materials. Ash is hauled to the fill site and compacted with normal construction equipment. Ash fills are capable of excellent performance with very little settling compared to

conventional materials. However, because the fly ash is not incorporated into a cementitious matrix, the fill must be designed to avoid environmental problems that could be caused by leaching.

In urban areas where competing materials are scarce and expensive, fly ash fills usually are economically feasible. The competition in this market is soil, sand and gravel—raw materials which are readily available and inexpensive in most areas. Except for projects very near a power plant, high transportation costs make this one of the less promising markets for coal ash in many western areas. Transportation subsidies from utilities with high disposal costs could improve the competitive position of this coal ash market.

Waste stabilization: A promising application for fly ash is for hazardous waste stabilization. Stabilizing hazardous materials by solidifying them into an environmentally inert mass has potential to become a use for fly ash as more Super-Fund and other RCRA environmental remediation takes place.

The chief competition in this evolving market is lime, portland cement, and kiln dust. While it has been estimated that several hundred thousand tons of fly ash per year are being used nationally for waste stabilization, lime continues to play a substantial role in the market because of its cementitious properties. With the present national average cost of all types of lime at $49.96 per short ton (1987), the use of coal ash for the stabilization of waste might become a profitable alternative (Baker/TSA, 1990). Demand for waste stabilization materials is certain to increase as stricter waste disposal regulations take effect.

Subgrade stabilization/Pavement base course: Besides being usable in both concrete and asphalt paving, coal ash can be used in the underlying roadway layers. Soils that are not suitable for roadway construction by themselves commonly are improved by adding lime or cement. Fly ash can be substituted for these more expensive materials and can be used without any other cementitious material if the lime content of the ash is high enough (GAI vol 1, 1992).

Another use of fly ash in road building is in pavement recycling on secondary roads that are being upgraded. The existing pavement is pulverized in place, then fly ash (and cement or lime, if needed) is mixed into the broken pavement to solidify and create a new base course. Just a few of the benefits of this process include: lower cost compared to other recycling methods, no additional aggregate is required, and large amounts of fly ash are productively used (GAI vol 1, 1992).

Roller compacted concrete: Roller compacted concrete (RCC) is a very stiff concrete that is laid with asphalt paving equipment (GAI vol 1, 1992). Because of the unique requirements of RCC, large amounts of very fine aggregate are required. Fly ash normally satisfies this requirement and contributes to overall strength because of its pozzolanic nature. RCC that contains fly ash has several advantages including: speed of construction, no finishing requirement, no need for expansion or contraction joints, and lower cost (GAI vol 1, 1992).

Another advantage of RCC with a high content of fly ash is its low heat of hydration. This is important for massive concrete structures such as dams. The Upper Stillwater Dam in Utah is made of RCC (GAI vol 1, 1992).

Other Applications

Coal combustion by-products can be used in a wide variety of products. These uses add

value to the by-product and may allow it to compete favorably in more profitable markets.

Applications include (but certainly are not limited to): use as a component of portland cement, lightweight aggregate, wallboard, autoclaved cellular concrete, mineral wool, and as a source of minerals.

Used in portland cement: Fly ash can be used as raw material in the manufacture of cement. The Portland Cement Association lists fly ash as a good source of alumina and silica, which are needed in cement (Kosmatka, 1990). FGD sludge can be a source of gypsum, another mineral needed when making cement.

In 1987, consumer demand for cement in the United States was estimated at 93.9 million tons. Of the 119.9 million tons of raw material used to produce 78.2 million tons of cement, 1 percent was fly ash (Baker/TSA, 1990). Using fly ash as a raw material can present considerable energy savings because the resource is obtained without mining. Cement plants near sources of coal ash may be able to reduce their raw material costs by using ash.

Lightweight aggregate: Lightweight aggregates are commonly used in the production of concrete masonry block. Progress Materials Inc. of St. Petersburg, Florida, produces a fly ash aggregate known as "Aardelite." The aggregate is produced by pelletizing and curing a mixture of fly ash and lime. Production of this aggregate began in 1988 and annually consumes approximately 100,000 tons of fly ash (Hay, 1992). The company claims this very competitively priced aggregate can be produced with fly ash contents of over 90 percent, depending on ash properties (American Coal Ash Association, 1987). For many years in the West, as in the rest of the country, there has been an active market for lightweight aggregate. Expanded shale has captured a large percentage of this market. The process of expanding shale requires a high energy input to heat the shale. Plants producing lightweight aggregate from fly ash can avoid these high energy costs and be very competitive with expanded shale and other lightweight aggregates.

Wallboard: FGD by-product contains large amounts of gypsum, the main ingredient in wallboard. Wallboard plants in Texas, Florida, Illinois and Europe have used gypsum extracted from FGD by-product. However, gypsum is a plentiful and inexpensive mineral. The U.S., Canada and Mexico possess large deposits of gypsum which are expected to satisfy demand for decades to come.

Most wallboard plants in the U.S. are located near gypsum mines and are owned by companies which also own the mines. A plant's proximity to the mine minimizes transportation costs, which are an important consideration for operations involving inexpensive minerals. Wallboard plants must be very close to either a gypsum source or a large wallboard market. The two wallboard plants in Wyoming are located within 10 miles of gypsum mines at Cody and Lovell. Together, they use 400,000 tons of gypsum to produce approximately 400 million square feet of wallboard annually, which is sold throughout the Northwest. The cost of drilling, blasting and transporting the gypsum is $2-3 per ton.

The operators of wallboard plants consider quality control, testing and consistency of supply when selecting a gypsum source. FGD by-product must meet specifications including purity, and content of free water and chloride. Georgia-Pacific's Gypsum Products plant in Lovell, Wyoming requires at least 90 percent gypsum in its raw material (Martin, 1992). The coal by-product that Georgia-Pacific tested from plants in the region ranged from 10-40 percent gypsum. Much of the by-product was not in the dry hydrate form required by the plant. Additional processing would be

required to make the FGD by-product suitable for use in wallboard production, driving up the cost.

Plentiful gypsum supply, vertical integration, transportation costs, and costs of quality control and testing limit the prospects for penetration of FGD by-product into the wallboard market.

Autoclaved cellular concrete: Another technology that uses fly ash is the manufacture of autoclaved cellular concrete (ACC). New to the U.S. but widely used in Europe and other countries, ACC is a lightweight insulating concrete product that can be worked with normal carpentry tools. As much as 75 percent of the solid material in ACC may be fly ash.

North American Cellular Concrete has constructed a mobile ACC plant that travels to power plants and makes building blocks from local ash in an effort to stimulate the potential U.S. market. A major obstacle to introducing ACC to the U.S. market is the high capital investment required. A full-sized ACC manufacturing plant costs between 10 and 20 million dollars, depending on the plant's production capabilities.

Mineral wool: Mineral (or rock) wool is normally produced from melted metals and blast furnace slag to produce a product similar to fiberglass insulation. Fourteen companies were manufacturing mineral wool in the United States in 1980 (ICF, 1987). Mineral wool has been manufactured experimentally from coal ash and has been shown to have better insulating properties than the same type of product made from conventional materials (ICF, 1987).

Producing mineral wool from coal ash instead of blast furnace slag has several economic advantages: little raw material preparation is required, additional fluxing agents are not necessary, and raw materials are located near all major markets (ICF, 1987).

Mineral extraction: The extraction of minerals from fly ash is still experimental. Aluminum and iron are of primary interest, but minor amounts of magnesium, sodium, potassium, and titanium also are present (ICF, 1987).

The processes that extract these minerals are expensive but possibly no more expensive than mining and importing these resources. Transportation costs are most important when transporting low value material. The feasibility of extracting an expensive material such as titanium would be relatively independent of transportation costs, compared to other less expensive materials.

THE COAL-COMBUSTION BY-PRODUCT MARKET

With over 250,000 tons of coal-combustion by-products being marketed each year (see Appendix A), Region 8 possesses an active coal-combustion by-product market with substantial ash resources and encouraging prospects for greater by-product use. The presence of quality by-products, vigorous marketers, and power plant managers eager to market their coal-combustion by-products indicate that the region is well-positioned to expand its use of coal-combustion by-products.

The market for coal by-products is not easily summarized by simple generalizations. The various qualities of by-product produced and used in different locations render each marketing effort unique and subject to varying site-specific considerations. These considerations include by-product quality, consistency and volume; availability of substitute products; local regulatory and economic environments; transportation; and storage facilities.

Power Plants that Produce Coal By-products

Discussions with representatives of coal-powered energy generating plants in the region revealed a strong desire to market by-products. Most of the plants produce by-products which have market potential; some of which are, in fact, currently being marketed. By viewing their coal by-product as a valuable commodity and adopting more aggressive marketing approaches, plant managers might be more successful in marketing their by-products. Steps to increase by-product sales may range from contacting marketers to investing in combustion and pollution control equipment which yield a more marketable by-product.

The cost of disposing of coal-combustion by-products is a strong consideration in the decision to market these by-products. For many plants, this is a very pressing matter. The closing of landfills and increasing restrictions on disposal practices are forcing plants to seek alternatives to their present disposal methods. Marketing coal-combustion by-products may be a way of avoiding disposal costs. The savings from avoided disposal costs can justify the costs of the utilities' marketing efforts.

The Electric Power Research Institute (EPRI) has produced several reports which offer guidelines for initiating a coal ash marketing program. According to the Coal Combustion By-products Utilization Manual (Baker M., 1984), the chief steps in such a program include initial market research and marketing constraint analysis.

In the initial market research the plant manager should assess the quality, timing and amount of by-product produced and determine which market it is best suited to serve. The initial market research also determines the financial viability of the marketing opportunity, using a basic formula:

Marketing Revenues = Marketing Costs - Avoided Disposal Costs

Marketing costs include all investment in facilities, manpower and activities necessary to establish and maintain the marketing effort. These include storage and handling facilities, hiring qualified quality control personnel, and contracting with a marketing firm. It can be inferred from

the equation that the costs of disposal, including monetary, social and public relations costs, might be high enough to warrant use of coal ash even when marketing revenues are low.

A marketing constraint analysis can identify barriers that might impede the plant's by-product marketing program. Potential constraints are: lack of utility support and quality assurance, technical barriers, lack of public acceptance and customer service, unfavorable economic factors, strong competition from competing materials, and liability. The utility first should address the constraints it can resolve itself and proceed to overcome any external constraints as its marketing effort becomes more ambitious.

A utility can serve its by-product marketing cause well by developing demonstration projects on its own premises. Use of by-products on roads, embankments, road de-icing, and in experimental projects could go a long way in demonstrating the various uses of by-products. Furthermore, this helps to develop expertise in the characteristics and handling of the by-products.

Marketers

Most power plants that market their by-products choose to contract with marketing firms that have knowledge of by-product applications and customer demand. For the utility, working with a marketer generally is less costly — but not necessarily more profitable — than developing its own by-product marketing department. In a typical marketing arrangement, a plant contracts with a marketer to sell its by-product. The payment terms will be either for a flat amount or on a "share of sale" basis by which the plant receives an agreed upon percentage of revenue from by-product sales. This percentage can vary widely but generally falls between 25-50 percent of gross sales revenue. The four main marketing firms actively marketing coal-combustion by-product in the region (see Appendix C) serve as a vital element in the current use of coal by-products. They promote exploration and development of new uses for coal by-products in the region and the expansion of current uses. Marketers also arrange quality control, transportation, storage and handling, and education and public relations.

Quality control is essential. The marketer, the supplier and the consumer must determine the criteria for the quality of the by-product and establish methods of testing and ensuring that the product meets the requirements. The marketer normally has the lead role in quality control.

Transportation costs are critical in determining the cost feasibility of ash use. In some cases, the cost of transporting the by-product may discourage its use. Rates for transporting by-product are negotiated with a trucking company or railroad on a specific point-to-point basis. These rates depend on the locations of the points of origin and destination, transport distance, volume of material, competition, and many other factors. The Interstate Commerce Commission, however, publishes tariff rates for rail transport of fly ash. These rates range from $1,000 per car for distances of 0-99 miles up to $6,000 per car for distances of 2,000 miles and greater. At 100 tons of fly ash per car, the rates range from $.03 to $.10 per ton per mile. Better rates may be negotiated for high volume transport, or if loads are available for back-hauling.

Storage and handling also affect the cost of marketing coal by-products. Much of the by-product is produced in the winter when demand for heat and electricity is high and the demand for construction materials is low. Conversely, in the summer when demand for construction materials is high, the supply of coal by-product is less plentiful. Adequate storage facilities are necessary to bridge the seasonal gap between supply and demand. Both marketers and utilities in the region have invested in storage facilities to promote their marketing efforts.

Costs for handling the by-product are included in storage and transportation costs. An important step in the process is the provision of adequate facilities for safely and efficiently loading, unloading and moving the by-product from the power plant to storage facilities and the consumer. Inadequate handling facilities can add considerably to transportation costs and may render by-product use unfeasible.

Marketers in the region currently focus on large concrete construction projects. At present, for example, much of the region's fly ash is being used in the Denver airport project. Coal by-product also is being used for other concrete projects, road sanding, and construction of road base and subbase. Marketers see the greatest potential in the region in increased use of by-products for transportation construction projects.

Marketers note the biggest constraints to increased use of coal-combustion by-products are the failure of ash to meet specifications, prohibitive transportation costs, availability of other raw materials in the region, reluctance of public agencies (such as departments of transportation) to use ash, lack of knowledge regarding ash use, and inadequate storage and handling facilities. These barriers can be overcome by expanding utilities' commitment to by-product marketing efforts and by informing government agencies and the public about coal-combustion by-products. Other barriers include the perception of coal-combustion by-products as waste.

STATE BY STATE OVERVIEW

The appendix contains information on the amount of coal-combustion by-products that are produced and used in each state. The amount of by-product produced and how much is used varies from year to year. How accurately each power plant records the amount of by-product used also varies considerably. With these limitations in mind, the information in the appendix gives a good estimate of the coal ash production and use in each state.

Colorado

The Denver Airport project dominates the coal ash market in Colorado. Western Ash Company is supplying more than 100,000 tons of fly ash from three generating plants operated by the Colorado Public Service Company and from plants in Wyoming and Montana. This project is expected to consume high quality ash through 1993. The success of this project might lead to increased use of the region's ash in other large concrete applications. The Colorado energy office should assist in finding new markets to replace demand for coal ash after the Denver Airport project is complete.

Other uses of ash in the state include fill, drilling mud and road construction, though much of the ash still is being landfilled. The Clark power plant at Canon City is faced with an urgent situation as its landfill is due to close in October of 1993. Finding a market for its ash is a better alternative than seeking another disposal site.

Montana

Four power plants at Colstrip, the Corette plant at Billings, and the Lewis and Clark plant at Sidney are the primary coal-combustion by-product producers in Montana. Of these plants, the four at Colstrip produce by far the most coal ash, mostly in the form of FGD sludge; however, under present regulations, use of Colstrip by-products is not allowed. Review of these regulations by the Montana energy office could lead to increase coal ash use in Montana.

Mineral Specialties of Billings is actively marketing the coal ash from the Corette and Lewis and Clark plants. The Denver Airport project and local concrete construction are the main markets being served. The Montana Department of Transportation uses ash primarily in concrete and as mineral filler in asphalt.

North Dakota

The power plants in North Dakota are not located near a major ash market. Because of this, most use is in local projects. Bottom ash is used for road sanding and as sand blasting grit. Fly ash has been used primarily in concrete paving and construction. The state highway department has been using fly ash in paving concrete for many years. The North Dakota energy office should coordinate with the state highway department to pursue more diversified uses of ash in road construction projects.

The Coal Creek station in Underwood has gained national attention with its on-site demonstration of high volume fly ash concrete and flowable fill. Many of the roads and parking lots on site have been paved with concrete in which 70 percent of the cement was replaced with fly ash. Contech Admixtures brings Coal Creek ash to the Minneapolis market by back-hauling it on rail cars that ship lime to the plant.

The University of North Dakota Energy & Environmental Research Center in Grand Forks performs coal ash research under commercial and federally funded projects. The center is very well equipped for research in many areas of coal ash use.

South Dakota

The coal-burning power plants in South Dakota are the Ben French plant at Rapid City, the Kirk plant at Deadwood, and the Big Stone plant at Big Stone City. While most of the ash is disposed of in on-site landfills, disposal ponds or in a nearby mine, bottom ash is hauled away to be spread on roads for sanding.

The South Dakota highway department is using fly ash primarily in concrete, and is actively developing flowable fill applications. Use of ash is expected to increase as experience is gained with flowable fill.

Power plant representatives expressed strong interest in marketing their ash, but they cite high carbon and alkali content and distance from sizable markets as barriers to marketing efforts.

The state of South Dakota owns a cement plant in Rapid City. The South Dakota energy office should encourage coal-combustion by-product use by exploring the possibility of using fly ash as a raw mineral source in cement production at the Rapid City plant.

Utah

Power plants in Utah burn bituminous coal that typically produces a Class F fly ash. Of the five plants in the state, only Intermountain Generating Station at Delta has an active ash marketing program. Pozzolanic International purchases approximately half of the fly ash, which is the amount that has a low enough carbon content to meet quality requirements. Fly ash that meets marketing specifications is stored in a silo on-site. The other power plants in the state are not actively marketing ash, but the Huntington Plant has successfully used ash on-site for road construction.

The state highway department uses fly ash in concrete. Fly ash use in the northern part of the state is by contractor's option. However, fly ash use in the southern portion of the state is mandatory to counteract alkaline aggregate in the concrete.

Inconsistent ash quality and high transportation costs must be overcome to increase the use of ash in Utah.

Wyoming

The subbituminous coal burned in Wyoming typically produces high quality fly ash that is used in several ways. Pozzolanic International and Western Ash Company are actively marketing

the ash for use at the Denver Airport, other concrete projects, local and state road construction, and road sanding. Power plants continue to demonstrate successful on-site use through various applications.

Even before the Denver Airport project, several power plants were marketing large percentages of their ash. Most ash is consumed during the summer construction season when ash demand frequently exceeds production. To meet this demand, some plants have invested in facilities to store ash produced in the winter. The Wyoming energy office should support higher overall ash use by working with utilities and coal ash marketers toward additional storage facilities.

Western Research Institute in Laramie, Wyoming researches uses of ash. Among the applications currently being explored by the Institute are hazardous waste remediation, and new applications of ash for gravel roads. More established roadway applications have been employed by the state highway department for several years. Ash use in Wyoming continues to expand in concrete, stabilized base course, and flowable fill.

Wyoming has good quality ash, and its use has been encouraged by on-site demonstrations at power plants and favorable attitudes by public agencies. Ash use probably will continue to grow in the state.

CONCLUSION

Market conditions for coal-combustion by-products can be improved. Four prominent issues that need to be addressed are: 1) environmental concerns; 2) performance concerns; 3) by-product quality; and 4) transportation costs. State agencies have important roles in addressing these issues. The success of coal ash use can be greatly promoted by the cooperation of state agencies such as the departments of energy, transportation, and environment/health. A state procurement program for coal ash use in infrastructure and government facilities projects should be designed and implemented to increase demand for coal ash and advance new economic and business development. States also should evaluate, write or revise their solid waste management plans to prevent any regulatory barriers to encourage the beneficial use of these coal-combustion by-products.

Many feasible coal ash use projects have not been implemented by government or private businesses because of environmental questions. As recommended in the EPA report to Congress, many of these environmental concerns should be addressed at the state level. State energy offices should coordinate efforts with state environment/health offices to respond to environmental concerns, establish consistent policies, and distribute accurate information.

Numerous studies — most notably, those by EPRI — have been undertaken to assess the performance of coal-combustion by-products under various conditions. However, because of the site-specific nature of each project, the ability of a given by-product to satisfactorily perform under local conditions must be verified. State energy offices should support research with research facilities and universities in their states to investigate the performance of coal-combustion by-product applications in local conditions. State energy offices also should coordinate with state transportation agencies to identify the most promising construction techniques that use available coal-combustion by-products and meet the performance requirements for local climatic and traffic conditions.

Utilities need to be active in improving conditions for coal ash use. Utilities producing by-products that do not meet ASTM Class C or F requirements still have alternatives to landfilling their by-products. High volume applications such as flowable fill and road base stabilization are potential markets capable of consuming large quantities of by-products that do not necessarily meet ASTM standards. Another option is for a utility to create or invest in a business that produces products — such as lightweight aggregate or wallboard — which can use large amounts of the utility's by-products. Another approach is to consider the marketability of the by-products when selecting new combustion and pollution control equipment. The inclusion of such a consideration in equipment selection and plant design would reflect a utility's commitment to the use of coal-combustion by-products and the perception of its by-products as resources rather than waste.

The role of utilities in overcoming the constraint of prohibitive transportation costs in marketing coal-combustion by-products is crucial. Utilities facing high disposal costs should consider subsidizing transportation expenses to improve the marketability of their product. Resources diverted from disposal costs toward transportation expenses can significantly increase the radius of the market area.

Coal-combustion by-products have been used for decades in many diverse applications. New applications continue to be developed. Expanded use of coal-combustion by-products stands to serve the interests of many parties by conserving energy and natural resources, providing an inexpensive source of raw materials, adding value to products, and providing an alternative to costly methods of by-product disposal.

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APPENDIX

A. Inventory of Fly Ash Production in Region 8, Montana Energy Division

B. 1990 Coal Combustion By-product — Production and Consumption, American Coal Ash Association

C. Coal Ash Marketers

D. Coal Ash Researchers

A. Inventory of Coal Ash Production in Region 8

Coal-Burning Generation Facilities	Tons of Ash Produced Annually FA= Fly Ash BA= Bottom Ash	% Marketed/Used Annually
COLORADO		
Clark Plant	10,500 FA 15,800 BA	< 3%
Drake, Martin	56,400 FA 6,300 BA	< 3%
Nixon, Ray D.	59,900 FA 3,200 BA	< 3%
Craig Plant	350,000 FA 80,000 BA	< 3%
Hayden Plant	140,000 FA 20,000 BA	< 3%
Nucla Plant	71,500 FA 30,700 BA	< 3%
Rawhide Energy Station	44,000 FA 8,000 BA	< 3%
Arapahoe Steam Plant	34,500 FA 11,500 BA	< 3%
Cameo-Palisade Steam Plant	10,500 FA 3,500 BA	< 3%
Cherokee Steam Plant	203,000 FA 67,500 BA	< 3%
Comanche Plant	67,500 FA 22,500 BA	40% FA
Pawnee Plant	74,300 FA 24,800 BA	85% FA 33-50% BA
Valmont Steam Plant	35,500 FA 11,800 BA	< 3%
MONTANA		
Colstrip Plant	670,100 FA 287,000 BA	0 (prohibited by regulation)
J.E. Corette Plant	32,600 FA 8,200 BA	60% FA 90% BA

Coal-Burning Generation Facilities	Tons of Ash Produced Annually FA= Fly Ash BA= Bottom Ash	% Marketed/Used Annually
Lewis & Clark Plant	10,300 FA 8,200 BA	80% FA 90% BA
NORTH DAKOTA		
Antelope Valley Plant	540,000 FA 180,000 BA	< 3%
Leland Olds Plant	115,000 FA 115,000 BA	< 3%
Coal Creek	550,000 FA 250,000 BA	15-20% FA
Milton R. Young Station	112,000 FA 168,000 BA	< 3%
Coyote Plant	97,600 FA 70,000 BA	< 3%
R.M. Heskett Plant	34,800 FA 23,300 BA	< 3%
Stanton Plant	200,000 FA 90,000 BA	< 3%
SOUTH DAKOTA		
Ben French Plant	3,800 FA 3,100 BA	< 3%
Kirk Plant	4,400 FA 4,400 BA	< 3%
Big Stone Plant	62,600 FA 146,000 BA	< 3%
UTAH		
Bonanza	108,000 FA 12,000 BA	< 3%
Intermt. Generating Station	320,000 FA 96,000 BA	47% FA
Carbon Steam Plant	37,500 FA 12,500 BA	< 3%
Hunter Plant	350,000 FA 150,000 BA	< 3%
Huntington Plant	250,000 FA 62,000 BA	< 3%

Coal-Burning Generation Facilities	Tons of Ash Produced Annually FA= Fly Ash BA= Bottom Ash	% Marketed/Used Annually
WYOMING		
Laramie River Plant	332,900 FA 83,200 BA	66% FA
Neil Simpson Plant	4,800 FA 1,200 BA	< 3%
Dave Johnston Plant	292,000 FA 91,300 FA	< 3%
Jim Bridger Plant	525,000 FA 131,000 BA	43% FA 5% BA
Naughton Plant	327,000 FA 81,800 BA	100% FA (in summer)
Wyodak Plant	126,200 FA 42,100 BA	< 3%
Osage Plant	30,000 FA, BA	< 3%

B. 1990 Coal Combustion By-Product—
Production and Consumption, American Coal Ash Association

1990 Coal Combustion By-product—Production and Consumption*

(SHORT TONS**)

REVISION NO. 1, June 15, 1992

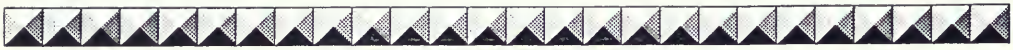
	FLY ASH	BOTTOM ASH	BOILER SLAG	FGD MATERIAL	
A. By-product Production	**48,931,722**	**13,705,653**	**5,234,316**	**18,932,688**	
Subtotal			**67,871,690**		
Total				**86,804,378**	
B. By-product Consumption	12,420,163	5,360,104	3,252,220	215,852	****
Subtotal			**21,032,487**		
Total				**21,248,339**	****
1. External Market					
a. Cement and concrete products	7,179,576	496,664	305,385	0	
b. Structural fills	427,189	414,651	0	0	
c. Road base/ Subbase	778,101	437,284	148,300	20,782	
d. Mineral filler in asphalt	127,833	2,734	19,138	0	
e. Snow and ice control	0	813,901	886,452	0	
f. Blasting grit/Roofing granules	0	175,154	1,661,691	0	
g. Grouting	338,864	0	0	0	
h. Coal mining applications	61,798	0	0	0	
i. Wallboard	0	22	0	43,925	
j. Miscellaneous/Other	645,902	367,749	73,525	86,270	
Subtotal	**9,559,263**	**2,708,137**	**3,094,490**	**150,977**	
2. Internal Utility Use					
a. Cement and concrete products	6,026	0	0	0	
b. Structural fills	2,253,375	1,074,908	6,184	29	
c. Road base/Subbase	56,908	560,133	1,094	62,213	
d. Snow and ice control	0	16,586	365	0	
e. Miscellaneous/Other	544,577	1,000,319	150,088	2,632	
Subtotal	**2,860,886**	**2,651,945**	**157,730**	**64,875**	
C. By-product Consumption as a Percentage of Production by Individual By-product	25.4%	39.1%	62.1%	1.1%	****
D. By-product Consumption as a Percentage of Fly Ash, Bottom Ash, & Boiler Slag Only			31.0%		

Comparative Results by Year***

E. By-product Production (million short tons) by Individual By-product and for Combined Production of Fly Ash, Bottom Ash & Boiler Slag Only	1987	1988	1989	1990
Fly Ash	50.11	50.91	53.38	48.93
Bottom Ash	14.72	14.27	14.21	13.71
Boiler Slag	4.12	5.03	4.27	5.23
Combined	**68.95**	**70.20**	**71.86**	**67.87**
F. By-product Consumption (million short tons) by Individual By-product and for Combined Production of Fly Ash, Bottom Ash & Boiler Slag Only				
Fly Ash	11.05	11.36	10.15	12.42
Bottom Ash	4.77	5.43	4.85	5.36
Boiler Slag	2.44	2.83	2.52	3.25
Combined	**18.26**	**19.83**	**17.52**	**21.03**
G. By-product Consumption (percent) as Percentage of Production by Individual By-product and as Percentage of Combined Production of Fly Ash, Bottom Ash, & Boiler Slag Only				
Fly Ash	22.0%	22.3%	19.0%	25.4%
Bottom Ash	32.4%	38.1%	34.1%	39.1%
Boiler Slag	59.2%	56.4%	59.0%	62.1%
Combined	**26.5%**	**28.0%**	**24.4%**	**31.0%**

Based on total coal burn of 772,000,000 short tons by domestic electric utilities, as reported by the National Coal Association
** short ton = 2,000 pounds.
*** metric tons = short tons X 0.9078
**** Data is also available for earlier years beginning in 1966
***** Revised data.

Compiled by the AMERICAN COAL ASH ASSOCIATION, INC., 1913 I Street, N.W., 6th Floor, Washington, DC 20006
Phone: 202-659-2303 FAX: 202-223-4984



C. Coal Ash Marketers

Jerry Vollmer
Mineral Specialties, Inc.
Box 1563
Billings, MT 59103
(406) 656-2334

Don McDonald
Western Ash Company
4380 South Syracuse Street
Suite 305
Englewood, CO 80155
(303) 779-8366

Ray Davis
Contech Admixtures/J.W. Brett, Inc.
8850 Wentworth Avenue, So.
Bloomington, MN 55420
(612) 884-0665

Dennis Augustine
Pozzolanic International
7525 24th SE
Suite 630
Mercer Island, WA 98040
800-426-5171

D. Coal Ash Researchers

Jerry Stephens
Montana State University
Department of Civil and Agricultural Engineering
Bozeman, MT 59717
(406) 994-6113

Frank Diebold
Montana Tech
Advanced Minerals & Hazardous Waste Processing Center of Excellence
W. Park Street
Butte, MT 59701
(406) 496-4215

University of North Dakota Energy & Environmental Research Center
15 North 23rd Street
Box 8213 - University Station
Grand Forks, ND 58202-8213
Debbie Hassett (701) 777-5261
Steve Benson (701) 777-5177
Bruce Dockter (701) 777-5000

Susan Sorini
Western Research Institute
P.O. Box 3395, University Station
Laramie, WY 82071
(307) 721-2232

Bruce Suprenant
University of Colorado
7720 Ferrisway
Boulder, CO 80303
(303) 494-5701